

Effects of Display Location and Information Level on UAS Pilot Assessments of a Detect and Avoid System

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Minimum display requirements and performance standards for Detect and Avoid (DAA) systems are currently being developed to safely integrate Unmanned Aircraft Systems into the National Airspace System (NAS). The present study examines UAS pilots' subjective assessments of four display configurations with either basic or advanced levels of information presented on a standalone or integrated display. Post-trial and post-simulation questionnaires queried pilots on their subjective ability to safely perform tasks and effectively utilize available information on each display. Responses indicated that the majority of pilots considered each display to be acceptable for a pilot-in-the-loop DAA task overall, but also revealed a strong preference for an integrated display with advanced information in the form of conflict resolution tools. Implications on the development of DAA display requirements, as well as the relation between the subjective evaluations and the objective performance data from previous studies are discussed.

INTRODUCTION

Subject matter experts from a consortium of academic, government, and industry institutions are developing new regulations to support the expansion and integration of Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS; RTCA, 2013). Current UAS operations in the NAS are limited to public purposes, such as military training, in restricted airspace. Potential benefits in civil and commercial applications and improved technologies have increased demand for UAS routine access to the civil airspace. The Federal Aviation Administration (FAA) UAS Roadmap (2013) outlines a plan for the development of minimum performance and operational standards that comply with existing airspace operations.

Current federal regulations for manned flight operations require onboard pilots to "see and avoid" other aircraft in order to remain well clear (14 CFR, Part 91, Sec. 91.113, 2004). Since UAS are flown without a pilot in the cockpit, applying these requirements to unmanned operations will require a "detect and avoid" (DAA) system with a self-separation (SS) function that allows UAS pilots to comply with minimum separation standards remotely while in-the-loop under normal operating conditions (Santiago & Mueller, 2015; RTCA, 2013). Specifically, the information provided by the DAA system must be adequate enough for pilots to detect a threat, determine a resolution to the conflict, and command the resolution maneuver to the UAS with the ground control station (GCS) vehicle control interface. However, the minimum amount of informational elements required for pilots to meet acceptable performance levels still need to be defined.

Recent studies have explored the minimum visual information requirements necessary to perform UAS pilot-in-the-loop DAA tasks. Predictive displays including a color-coded alerting structure, airspace warning zones, and relative closest-point-of-approach (CPA) indicators along with

intruder state information and directionality have reduced near midair collisions (NMACs), well clear violations, and time spent within the well clear boundary compared to displays with less information (Bell, Drury, Estes, & Reynolds, 2012; Friedman-Berg, Rein & Racine, 2014). Similarly, an operator information requirements survey conducted by Draper, Pack, Darrah, Moulton and Calhoun (2014) revealed that the majority of pilots prefer intruder state information and visual alerts to be displayed at all times, however respondents also designated flight restrictions, weather, and DAA maneuver recommendations as critical information elements.

The aforementioned studies have provided a framework from which to build toward specifying the minimum DAA display elements required in a GCS for safe integration into the NAS. Display location is another DAA display aspect that must be considered when developing new operational standards. Although an independent, standalone display may be easier to implement compared to the modifications that would be required to integrate a DAA display into existing GCS software, there is a high likelihood that it would be decoupled from the GCS command and control interface. The potential demand of reviewing relevant information on a display separate from the vehicle control display may introduce detriments in pilot performance and response times (Fern, Rorie, Pack, Shively, & Draper, 2015; Santiago & Mueller, 2015). The current study reports the subjective results of Fern et al. (2015), which explored the implications of DAA display location and information level on pilots' ability to properly perform mission critical tasks.

METHOD

Participants

Twelve active duty RQ-4 Global Hawk pilots ($M_{age} = 39$ years old) with either a pilot certification or Instrument Rating

through the military and an average of 216 hours experience flying UAS in combat and non-combat operations were recruited for the study. Eight of the pilots had an average of 60 hours previous experience flying UAS in civil airspace. One retired Air Traffic Controller (ATC) with experience at the Oakland Air Route Traffic Control Center (ZOA) and three pseudo-pilots served as confederates.

Apparatus

Refer to Fern et al. (2015) for a detailed description of the simulation architecture, airspace environment, and GCS configuration consisting of NASA’s Cockpit Situation Display (CSD; Figure 1a; Johnson, Battiste, & Bochow, 1999) and the Air Force Research Laboratory’s Vigilant Spirit Control Station (VSCS; Figure 1b; Feitshans, Rowe, Davis, Holland & Berger, 2008).

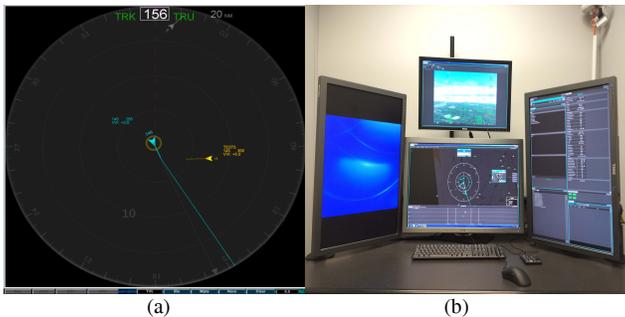


Figure 1. (a) Cockpit Situation Display with an active SS threat, (b) Vigilant Spirit Control Station

Experimental Design

Detect and Avoid System. The threat detection system supplied by the Java Architecture for DAA Modeling and Extensibility (JADEM; Santiago, Abramson, Refai, Mueller, Johnson & Snow, 2015) applied a multi-level alerting structure to aircraft within an ADS-B-like surveillance range of 80nm laterally and +/- 5000 feet vertically (Table 1). The threat levels associated with the surrounding traffic were based on the intruder’s predicted lateral (nm) and vertical (ft) closest-point-of-approach (CPA) distance from ownship and time-to-CPA (sec).

| Alert/Threat Level | CPA Distance | | Time to CPA | Color |
|---|--------------|----------|-------------|----------------------|
| | Lateral | Vertical | | |
| Proximal | > 2 NM | > 900 FT | N/A | Grey |
| Preventative | < 2 NM | < 900 FT | < 120 secs | White |
| Self-Separation | < 1.2 NM | < 900 FT | < 110 secs | Yellow |
| *Predicted Collision Avoidance (Advanced) | < 0.8 NM | < 400 FT | <110 secs | Yellow w/ Red Border |
| Collision Avoidance | < 0.8 NM | < 400 FT | < 40 secs | Red |

Table 1. The multi-level conflict alerting logic.

Information Level. In addition to range rings with adjustable display ranges, pilots were provided with either basic or advanced levels of information on the display to support their ability to maintain well clear. The basic display configuration contained a minimum set of intruder traffic information (Friedman-Berg et al., 2014; Draper et al., 2014; Fern et al., 2015). The intruder location, range, bearing, heading, relative altitude, vertical trend, heading predictor, and threat level were always visible to the pilots. The intruder data tag displayed the ground speed, vertical velocity, absolute altitude, and aircraft ID.

The advanced display configuration contained all of the basic information elements along with additional information and features to aid separation maintenance during active threats, i.e. predicted CPA location and time-to-CPA indicators, an added collision avoidance (CA) alert level for threats predicted to penetrate the well clear volume (predicted CA), a 0.8nm “well clear ring” around ownship, a recommended maneuver derived from the Autoresolver-AD conflict resolution algorithm (Santiago et al., 2015), vertical situation display, and trial planning tools that predicted the associated threat level at a proposed heading or altitude. The vertical trial and lateral trial planning tools employed a color-coding scheme that matched the alerting logic on the traffic icons. When dragging the lateral vector planner tool to a desired heading, the route line/vector arrow’s color would change according to the predicted alert level after execution of the command at the proposed trajectory (as shown in Figure 2). Pilots could then use their discretion when choosing whether to upload the recommended maneuver or further evaluate alternate safe headings and altitudes using the trial planning tools. A full description of the advanced display features and their functions can be found in Fern et al. (2015).



Figure 2. Lateral vector planner tool during a predicted CA alert (advanced integrated display). Yellow arrow indicates the proposed heading would result in a SS threat.

Display Location. Available information was presented to pilots either on a standalone or integrated display. The standalone display conditions presented pilots with the appropriate traffic information and conflict resolution tools (when applicable) on the CSD, while vehicle control maneuvers were executed via the VSCS Tactical Situation Display (TSD) on a separate monitor to the right. The integrated conditions presented all appropriate display features on the VSCS TSD, where pilots could review information and utilize available tools within the command and control

interface. The trial planning tools in the integrated condition were coupled to the TSD's auto-pilot interface, such that proposed headings and altitudes were automatically pushed to a steering window as the tools were being used. This coupling was not present in the standalone condition.

Procedure

Training. After completing an informed consent and demographics form detailing their aviation experience, participants were given a briefing on the schedule for the day and the pilot tasks they would be expected to perform (detailed below). Participants were then trained extensively on the basic functionality of VSCS. Participants interacted with the interface during training to demonstrate proficiency with the vehicle control interface and secondary tasks. Once familiar with the interface, pilots were briefed on the distinctive features of the display configuration that would be used in the upcoming experimental trial. Practice scenarios lasting up to 20 minutes were completed before each experimental trial.

DAA Pilot Task. Participants completed four 38-minute scenarios, each with a separate DAA display condition: basic standalone, advanced standalone, basic integrated, and advanced integrated. Pilots were instructed to fly a MQ-9 Reaper along a pre-filed mission route under Instrument Flight Rules (IFR) for each experimental trial. Two different flight paths were presented to pilots, one designed around a fire-monitoring mission and the other a coastal surveillance mission. There were approximately eight traffic encounters scripted to trigger SS alerts within each scenario. The encounters varied in angle, velocity, and relative altitude. Participants were instructed to comply with ATC clearances and traffic display alerts to maintain safety of flight while remaining on the planned route at the mission altitude and route as much as possible. Pilots were also required to monitor and respond to chat, health, and status tasks during the experimental scenarios (detailed in Fern et al., 2015).

MEASURES

Post-Trial Questionnaire

Following each experimental trial, participants completed a post-trial questionnaire with subjective ratings pertaining to the preceding display configuration.

Training Sufficiency. Pilots were asked to rate their agreement to the statement, "I felt I had enough training with this display to be able to operate it safely during this trial," on a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree).

Initial Alert Response. Pilots were asked to rate their agreement to the statement, "This display allowed me to respond immediately to collision avoidance threats," on a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree).

Conflict Assessment and Avoidance. Pilots also rated "the degree to which each of the following features contributed to your ability to most appropriately assess and avoid conflicts"

on a 4-point scale (1 - Not at All to 4 - Quite a Bit): lateral planning tool, vertical planning tool, intruder CPA, time to CPA, predictive CA outline on CPA, vertical situation display, ownship CPA, ownship 30 sec horizontal predictor line, well clear circle.

Ease of Use. Pilots also rated their agreement to a number of statements stating that each of the aforementioned features were "easy to use" on a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree).

Clutter. Additionally, pilots rated their agreement to the statement, "I did not find this display overly cluttered," on a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree).

Performance Degradation. Pilots were also asked to rate, on a 5-point scale (1 - Unacceptable to 5 - Excellent), their acceptability of the alert timing and ability to "perform numerous mission-critical tasks (including chat, radio changes, alerts, range/bearing)", "minimize deviations from the planned path", and "maintain safe flight operations" under each display configuration.

Post-Simulation Questionnaire

Following the final experimental trial, a post-simulation questionnaire queried the pilots' agreement with a number of statements regarding the alerting logic, as well as preferences for airspace display information location and advanced display features.

Alerting Logic. Pilots answered 'Yes' or 'No' to the question, "Did the alerting threshold used in this study allow you sufficient time to assess the situation and maintain well clear?". Pilots also rated their agreement with the each of the following statements on a 5-point Likert scale (1 - Strongly Disagree to 5 - Strongly Agree):

- "The intruder alerting (i.e. icon color: grey, white, yellow, red) was easy to understand"
- "I clearly understood the alerting logic and meaning of each alert level (i.e., preventative, self-separation, collision avoidance)"
- "The visual alerting provided sufficient information to maneuver to avoid well clear violations"
- "The auditory alerting was intuitive and easy to understand"
- "The auditory alerting provided sufficient information to maneuver to avoid well clear violations"

Display Location. Pilots were asked to "check the location you most preferred for Airspace Display Information" on a 5-point scale (1 - Strongly Prefer Separate Display to 5 - Strongly Prefer Integrated Display). Additionally, pilots rated "which Airspace Display Location would result in the safest operations" on a 5-point scale (1 - Much Safer with Separate Display to 5 - Much Safer with Integrated Display).

Information Sufficiency. For each display configuration, pilots answered 'Yes' or 'No' to statements asking whether it "provided sufficient information and alerting to remain well clear".

Advanced Display Features. Pilots responded to the statement, “From the following list, please pick no more than 4 display features, in order of preference, that offer the highest potential to assist you in your ability to remain well clear: Predictive outlining of intruder to indicate potential CA, Vertical situation display, Predictive outlining of intruder to indicate potential CA, vertical trial planner, time to CPA, lateral trial planner, predictive outlining of CPA to indicate potential CA, ownship 30-second horizontal predictor line, well clear boundary circle, ownship CPA symbol, intruder CPA symbol.”

RESULTS

Pilot responses to post-trial and post-simulation questionnaires were analyzed using a one-way repeated measures Analysis of Variance (ANOVA).

Post-Trial Questionnaire

Training Sufficiency. While every display received at least slightly sufficient training ratings on average, pilots indicated the basic integrated display training ($M = 4.75$, $SEM = 0.13$) was more sufficient for safe operations compared to the training for the advanced standalone display ($M = 4.00$, $SEM = 0.25$), $F(3,33) = 5.463$, $p = .004$.

Initial Alert Response. There was also a significant main effect of display configuration on pilots’ perceived ability to respond immediately to CA threats, $F(3, 33) = 3.11$, $p = .039$. On average, pilots indicated that they were more able to respond immediately to CA threats with the advanced integrated display ($M = 4.83$, $SEM = 0.11$) compared to the basic standalone ($M = 4.08$, $SEM = 0.32$) and basic integrated displays ($M = 4.00$, $SEM = 0.23$).

Conflict Assessment and Avoidance. Of all advanced display features, display configuration only had a significant effect on the perceived conflict assessment and avoidance contributions of the lateral and vertical planning tools, p ’s $< .05$. The lateral planning tool contributed to perceived conflict assessment and avoidance more on the advanced integrated display ($M = 3.33$, $SEM = 0.23$) than the advanced standalone display ($M = 2.42$, $SEM = 0.19$), $F(1, 11) = 12.44$, $p = .005$. Pilots also identified the vertical planning tool as more useful for assessing and avoiding conflicts with the advanced integrated display ($M = 3.42$, $SEM = 0.23$) compared to the advanced standalone display ($M = 2.63$, $SEM = 0.27$), $F(1, 11) = 6.03$, $p = .032$.

Ease of Use. Display configuration had marginal effects on the ease ratings of both trial planning tools, $.05 < p$ ’s $< .10$. The advanced integrated display ($M = 4.33$, $SEM = 0.44$) yielded higher agreement rates to the statement “The lateral planning tool was easy to use” compared to the advanced standalone display ($M = 3.11$, $SEM = 0.42$), $F(1, 8) = 4.57$, $p = .065$. Likewise, pilot ratings indicated that the vertical planning tool was easier to use in the advanced integrated display condition ($M = 4.64$, $SEM = 0.28$) compared to the advanced standalone display condition ($M = 3.73$, $SEM = 0.30$), $F(1, 10) = 4.81$, $p = .053$.

Clutter. There was a marginal difference in clutter ratings found between the basic standalone and advanced standalone displays, $F(3,30) = 2.86$, $p = .054$. Advanced standalone displays ($M = 3.64$, $SEM = 0.41$) were rated more cluttered than the basic standalone displays ($M = 4.64$, $SEM = 0.15$).

Performance Degradation. Display configuration did not have a significant effect on the pilots’ alert timing acceptability or subjective ability to avoid intruder conflicts, minimize path deviations, or handle pilot tasks, p ’s $> .05$.

Post-Simulation Questionnaire

Alerting Logic. With regard to the alerting threshold, 83% of pilots reported that it allowed sufficient time to assess the situation and maintain well clear across all displays overall. Moreover, all pilots either somewhat or strongly agreed with each of the statements with regard to the sufficiency of the visual and auditory alerting information.

Display Location. All pilots reported either a slight or strong preference for airspace information being located on an integrated display ($M = 4.58$). Furthermore, all pilots rated operations as being either slightly safer or much safer with an integrated display ($M = 4.67$).

Information Sufficiency. Overall, the majority of pilots indicated that each individual display configuration provided sufficient information and alerting to remain well clear. The advanced integrated display, however, yielded the strongest consensus with 92% agreement among pilots, while only 64% of pilots agreed that the basic standalone display information and alerting was sufficient (Figure 3).

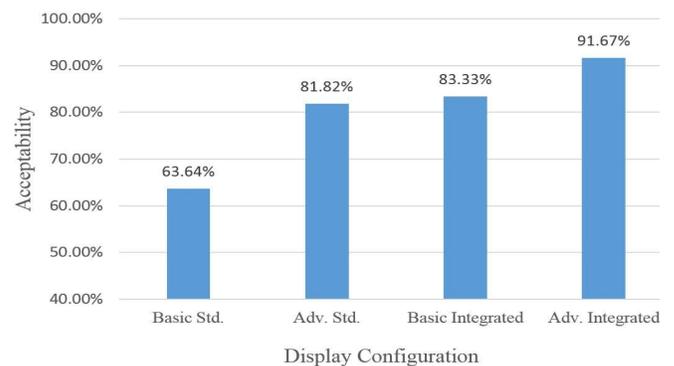


Figure 3. Percentage of pilots that rated the information and alerting as sufficient by display configuration.

Advanced Display Features. Overall, pilots ranked the intruder predictive outlining that indicated potential collision avoidance as the most preferable advanced display feature for well clear maintenance; it received a top-4 vote from 7 of 12 pilots, 5 of which being a ‘#1’ ranking. The next four most preferred display features, based on total top-4 rankings, were the vertical situation display (6 votes), lateral and vertical trial planners (5 votes apiece), and time-to-CPA (5 votes).

DISCUSSION AND CONCLUSION

The pilots’ subjective assessments of the four display conditions reveal consistent preference for an integrated

display, especially when advanced information was available. While there was a general consensus among pilots that each display configuration contained sufficient information and training to perform pilot tasks, they rated the additional features (e.g. trial planning tool) and advanced information on the integrated display as easier to use. Pilots also rated the integrated display as more conducive to safe operations. The perceived safety ratings align with the findings of Santiago and Mueller (2015), which revealed a 20% decrease in Loss of Well-Clear (LoWC) rates on the integrated display. There were several reasons cited, such as fewer mouse clicks, less distraction, and faster crosschecks when information was presented on an integrated display. Requiring pilots to review dynamic information on a monitor separate from the command-and-control interface appeared to introduce additional cognitive demand.

Although one pilot reported that the advanced tools were a distraction, the benefits of the advanced display features were seen with both advanced display configurations; though they were most prevalent when presented on an integrated display. Nearly every pilot indicated the advanced integrated display was the most preferable. Pilots felt the advanced display allowed them to respond to collision avoidance threats more immediately, especially on the integrated display. The duration of well clear violations in the integrated display condition was significantly reduced with the addition of advanced information (Santiago & Mueller, 2015). Information level only affected initial edit time (time between traffic alert and initiation of an edit) when presented on the integrated display (Fern et al., 2015). The added alert level predicting potential CA threats was voted the most beneficial display feature, and was instrumental in their ability to adhere to separation standards. This also aligns with the objective findings, which revealed a 45% decrease in LoWC frequency in advanced conditions (Santiago & Mueller, 2015).

Pilot ratings revealed that advanced information added a significant amount of clutter to the standalone display. The standalone advanced display was also viewed as the condition with the least sufficient training allowed to operate safely. Pilots reported that the vertical and lateral vector planning tools were somewhat easier to use and a more significant contribution to their ability to assess and avoid conflicts when located on the advanced integrated display compared to the advanced standalone display. The advanced integrated display also yielded the highest ratings on perceived ability to minimize deviations from the planned flight path, though the differences were not significant.

Although pilots felt they could perform their tasks with any of the display configurations, the objective findings reported by Fern et al. (2015) reveal that an integrated display with conflict detection and resolution tools provides the most support for DAA pilot task performance. Advanced tools may overload the pilot task when presented on a standalone display. The additional features appear to increase the workload associated with monitoring separate displays. The results imply that advanced tools are simply more intuitive when integrated with the GCS command-and-control interface. There are also numerous design considerations that would need to be addressed for the implementation of a

standalone display, such as matching the zoom levels and orientations.

While pilots indicated the predictive information and trial planning tools were helpful, their preference levels varied between display features. In addition, although the conflict detection and alerting tools were most preferable and effective when integrated with the TSD's auto-pilot interface, it is possible that standalone displays may benefit from resolution tools different from those implemented in the current study. It must be determined which conflict resolution tools make significant contributions to the observed benefits on performance and subjective assessments in the advanced display configuration. Rorie and Fern (2015) have since investigated the distinct impact of the vector planning tools and direct maneuver guidance found in the present study's advanced information condition. Further research is needed to identify the minimum DAA display requirements necessary for safe and efficient UAS operations in the NAS.

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